Mechanisms of Anterior Cruciate Ligament Tears in Professional National Basketball Association Players: A Video Analysis

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A systematic search was performed of online databases for any anterior cruciate ligament (ACL) injuries within the NBA. Video was obtained of injuries occurring during competition and downloaded for 2-dimensional video analysis. Thirty-five in-game videos were obtained for analysis. Of the reviewed cases, 19% were noncontact ACL injuries where there was no player-to-player contact from an opposing player. Three injury mechanism categories were found based on the events at the point of initial ground contact of the foot of the injured limb: single-leg casting (mean dorsiflexion angle 18.9° (14.4°); mean knee flexion angle 15.6° (7.8°); and mean trunk lateral flexion 18.2° (8.4°)); bilateral hop (mean dorsiflexion angle 18.2° (15.2°), mean knee flexion angle 21° (14.5°), mean trunk extension angle 6.9° (11.4°), and landing angle from the athlete’s center of mass 47.9° (10.1°)); and single-leg landing after contact (mean abduction angle of the swing leg 105.4° (18.1°), mean knee flexion angle of the injured limb 34.2° (8.0°), and mean trunk ipsilateral flexion angle 22.2° (7.0°)).

Keywords: athletic injuries, sports biomechanics, knee injury mechanics, tibiofemoral rotation

Professional basketball players are at high risk for noncontact traumatic knee injuries due to the high-energy change of direction maneuvers and mechanical loads imparted on the knee.1–3 While other lower limb injuries have a higher incidence in basketball, anterior cruciate ligament (ACL) tears have a significant performance and economic impact on players and teams due to the increased time lost to injury.5–8 The primary focus of studies examining ACL injuries in the NBA has been on the return-to-play process and performance outcomes postinjury.9–13 The average length of the rehabilitation phase prior to return-to-play after an ACL injury in the NBA is 9 months.10 Furthermore, athlete performance in the NBA has been shown to decline post-ACL injury.11,12

Retrospective video analysis has been used in various elite sport settings to identify ACL injury mechanisms, including 2-dimensional video analysis in soccer,14–16 basketball,13 and alpine ski racing.17,18 Using this method, Krosshaug et al13 examined sex differences in ACL injury mechanisms in basketball players in a heterogenous athlete population including mostly high school and collegiate athletes. It was reported that female players displayed greater knee and hip flexion angles at the time of injury. Valgus collapse of the knee was consistently observed in the female cohort at 50 ms after initial foot contact, but in only 2 out of 13 male injuries.10 However, recent evidence questions the relationship between knee valgus and ACL loading,19 and the kinematics and events leading to ACL injury among elite professional male basketball players in the NBA has not been elucidated.

Identifying the events leading to ACL injury and the injury mechanisms can help inform new strategies to prevent traumatic knee injuries in the NBA. Therefore, the purpose of this study was to use 2-dimensional video analysis of ACL injury events in professional NBA basketball players to characterize factors leading to ACL injury and to quantify the lower limb kinematics at the time of ACL injury. We expected indirect player-to-player body contact (not to the injured knee) to be present immediately before and during the ACL injury in most ACL injuries. Furthermore, based on previous research13,20,21 we expected to find a combination of a small angle of knee flexion (an extended knee), knee valgus, hip adduction, and hip internal rotation at the time of ACL injury.

Methods

Data Collection

A systematic search was performed of a publicly available online database (available at https://www.basketball-reference.com/friv/injuries.fcgi) for all ACL injuries occurring in the NBA from 1975 to 2022. All available in-game video was retrieved for each identified injury. Videos were not used for analysis if either the view of the injury was obstructed or there was direct player-to-player contact with the knee during injury (ie, a contact ACL injury). Indirect player-to-player contact to body regions other than the knee joint were included in the present analysis.

Video Analysis

Three reviewers with 10 years of experience in biomechanical analysis of high-performance basketball performed the video analysis (Petway, Epsley, and Anloague). Videos were downloaded to a personal computer and uploaded to MyDartFish 360 (DartFish; dartfish.com 5.0.1.0), a movement analysis software used to measure joint angles and limb positions.22,23 Evidence of indirect player-to-player contact prior to or during injury was noted for each injury. Injury mechanisms were categorized based on the sequence of movements leading to injury and the lower limb kinematics at the point of ground contact during the time of injury. The kinematic features of each identified injury mechanism were described and the
joint angles during each injury event were examined using the digital goniometer feature of the video analysis software.

**Results**

One-hundred and five ACL injuries were identified among 98 players in the NBA between 1975 and 2022. Seven players sustained multiple ACL injuries. Thirty-five in-game ACL injuries were obtained for film review and 8 videos were excluded due to either an obstructed view or direct player-to-player contact with the knee during injury. The mean age of the players in the remaining sample (n = 27) was 25 (4) years and their experience in the NBA at the time of injury was 5 (3) seasons. ACL injuries with no player-to-player contact occurred in 5 out of 27 cases (19%), indirect player-to-player contact (not directly to the knee) occurred prior to the injury in 21 out of the 27 (78%) injuries, indirect player-to-player contact during the injury in 10 out of 27 (37%) instances, and contact both prior to and during injury in 9 out of 27 occasions (33%). Internal tibiofemoral rotation at ground contact at the time of injury was observed in 18/27 (66%) cases.

Based on the injury sequence, 3 separate categories of injuries were determined based on the sequence of movements leading to injury and the lower limb kinematics at the point of ground contact during the time of injury: (1) single-leg casting, (2) a bilateral pro-hop, and (3) single-leg landing after contact.

**Single-Leg Casting**

The single-leg casting mechanism represented 48% of the ACL injuries analyzed in this study (13 out of 27). Notably, all 7 ACL re-injuries occurred with this mechanism. This was observed to be a unilateral stance during the injury event at the instance of ground contact during which the foot of the injured limb was anterior to the body center of mass (COM) immediately prior to the injury event and concurrently with a flexed hip joint, an abducted hip joint, or a combination of a flexed and abducted hip. These angles were measured in addition to lateral trunk flexion, knee flexion, and ankle dorsiflexion angles. These joint angles and kinematic features were determined to be relevant in all single-leg casting injury events. The average dorsiflexion angle was 18.9° (14.4°); the average knee flexion angle was 15.6° (7.8°); and the average trunk ipsilateral flexion angle toward the injured limb was 18.2° (8.4°). Player-to-player contact was observed in 69% (9/13) of the single-leg casting injury occurrences. Contact prior to injury was present in (9/13) injuries, whereas contact during the injury was found in (6/13) single-leg casting injuries. It was also observed that 6 of the 13 instances included contact prior to and during injury. A summary of the joint angle measurements for each injury occurrence are provided (Table 1) and a silhouette of the mean joint angles occurring during the single-leg casting mechanism are presented (Figure 3). Finally, the sequence of movements associated with the single-leg casting mechanism are illustrated (Figure 3).

**Bilateral Hop**

The bilateral pro-hop occurred in 29% of the injuries (n = 8). This was observed to be a bilateral stance during the injury event occurring during a hopping movement followed by a sudden deceleration of the COM with both feet in parallel or slightly offset. The foot position relative to the COM, ankle dorsiflexion angle relative to the shank, knee flexion angle, and trunk angle were measured at the instant of ground contact.

On average, the dorsiflexion angle was 18.2° (15.2°), the knee flexion angle was 21.0° (14.5°), the trunk extension angle was 6.9° (11.4°), and the angle based on the landing distance relative to the athlete's COM was 47.9° (10.1°). Player-to-player contact was observed in (6/8) of the bilateral hop injuries. This is represented by (6/8) injuries having contact prior to injury, (4/8) situations with contact during the injury, and (3/8) sustaining contact both prior to and during the injury. A summary of the joint angle measurements for each injury occurrence is shown (Table 2) along with the mean of the joint angles (Figures 4 and 5) and sequence of movements associate with this injury mechanism (Figure 6).

**Single-Leg Landing After Contact**

The single-leg landing after contact mechanism was the least common (6 out of 27). The single-leg landing after contact

<table>
<thead>
<tr>
<th>Athlete</th>
<th>Contact (pre/during)</th>
<th>Dorsiflexion (injured leg)</th>
<th>Knee flexion (injured leg)</th>
<th>Trunk lateral flexion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Athlete 1</td>
<td>Pre; during</td>
<td>38.7</td>
<td>11.6</td>
<td>11.6</td>
</tr>
<tr>
<td>Athlete 2</td>
<td>Pre</td>
<td>18.4</td>
<td>21.1</td>
<td>12.6</td>
</tr>
<tr>
<td>Athlete 3</td>
<td>Pre; during</td>
<td>17.5</td>
<td>6.5</td>
<td>8.3</td>
</tr>
<tr>
<td>Athlete 4</td>
<td>Pre; during</td>
<td>Obstructed</td>
<td>Obstructed</td>
<td>13.9</td>
</tr>
<tr>
<td>Athlete 5</td>
<td>Pre; during</td>
<td>Obstructed</td>
<td>8.7</td>
<td>20.1</td>
</tr>
<tr>
<td>Athlete 6</td>
<td>No</td>
<td>Obstructed</td>
<td>25.1</td>
<td>36.9</td>
</tr>
<tr>
<td>Athlete 7</td>
<td>Pre</td>
<td>10.2</td>
<td>25.8</td>
<td>13.6</td>
</tr>
<tr>
<td>Athlete 8</td>
<td>No</td>
<td>8.3</td>
<td>17.9</td>
<td>Obstructed</td>
</tr>
<tr>
<td>Athlete 9</td>
<td>Pre</td>
<td>8.5</td>
<td>16</td>
<td>16.8</td>
</tr>
<tr>
<td>Athlete 10</td>
<td>Pre; during</td>
<td>47.6</td>
<td>1.1</td>
<td>17.9</td>
</tr>
<tr>
<td>Athlete 11</td>
<td>No</td>
<td>Obstructed</td>
<td>20.7</td>
<td>30</td>
</tr>
<tr>
<td>Athlete 12</td>
<td>No</td>
<td>12.9</td>
<td>22.6</td>
<td>Obstructed</td>
</tr>
<tr>
<td>Athlete 13</td>
<td>Pre; during</td>
<td>8.1</td>
<td>12.3</td>
<td>18.6</td>
</tr>
</tbody>
</table>

Abbreviations: ACL, anterior cruciate ligament; contact (pre/during), pre: player-to-player contact occurred prior to injury, during: player-to-player contact occurred during injury; No, no contact occurred; dorsiflexion (injured leg), angle of tibia relative to the ankle axis on the injured limb; knee flexion (injured leg), knee angle relative to the hip and ankle on the injured limb; trunk lateral flexion, trunk lateral flexion during time of injury.
mechanism was defined as player-to-player contact in body regions other than the knee joint occurring while the injured player was airborne (both feet off the ground) followed by a single-leg landing event (ie, an off-balance single-leg landing). The knee flexion angle of the injured limb and lateral trunk flexion angles were measured along with the abduction angle of the noninjured limb (ie, the limb that remained in the air).

A summary of the joint angles for each injury occurrence is shown (Table 3), along with the average joint angles (Figures 7 and 8) and the sequence of events leading to this injury (Figure 9). The average abduction angle of the swing leg was 105.4° (18.1°), whereas the knee flexion angle upon whole foot ground contact of the injured limb was 34.2° (18°). The average trunk ipsilateral flexion toward the injured limb in single-leg landing after contact was 22.2° (7.0°).

**Discussion**

The present study consisted of 2-dimensional video analysis to quantify the ACL injury, associated kinematics, and potential injury mechanisms occurring among professional basketball players in the NBA. This study provides new information and a novel perspective on the factors contributing to the etiology of traumatic knee injuries in this population. Our findings include the identification of 3 distinct ACL injury mechanism classifications including single-leg casting, bilateral hop, and single-leg landing after contact. Each injury mechanism was characterized by a specific sequencing of movements that occurred at the time of ground contact and ACL injury. In all 3 mechanisms, the injured limb contacted the ground during a deceleration event outside of the base of support.

The single-leg casting mechanism involved a large angle of ankle dorsiflexion and heel strike ahead of the athlete’s COM. This was coupled with lateral flexion of the trunk in the direction toward the injured leg. In a prospective single-leg depth jump 2-dimensional video analysis, female athletes who went on to injure their ACL were found to have increased trunk lateral flexion toward the side of injury upon landing. Notably, the average knee flexion angle in the single-leg casting group was very low at the time of injury (15.6°). This is consistent with previous data demonstrating mean knee flexion angle in male basketball players at ground contact to be 9°, and only 19° at the proposed time of injury 50 ms later. Hashemi et al described a dynamic ground reaction force accompanied by the contraction of the quadriceps muscles at low angles of knee flexion as a major cause of anterior tibial translation in the mechanism of ACL rupture. The combination of a large ground reaction force placed on a relatively extended knee, with trunk lateral flexion are each well-recognized components of ACL injury and likely explain ACL rupture in this mechanism category.

The bilateral hop was typically performed during an offensive maneuver around the rim when the athlete possessed the ball and was attempting to reduce their forward momentum to initiate a basketball shot. This mechanism also occurred with a large angle of ankle dorsiflexion similar to that seen in the single-leg cast, but with both feet making ground contact ahead of the COM, a much higher mean knee flexion angle, and the trunk extended in a rearward position. Such a mechanism in ACL injury has been described as the “hip extension, knee flexion paradox.” It is purported that large braking forces cause the knee to flex and decelerate the pelvis at a rate much faster than hip flexion is occurring. In this sense, the hip is relatively extended, a position exaggerated by posterior trunk lean in the bilateral hop cohort.
When studying a stop-jump landing, Yu and Garrett identified that hip joint motion at foot contact affected ACL loading to a larger extent than the knee and hip flexion angles. Lower hip flexion angular velocity was associated with higher posterior and vertical ground reaction forces, which was subsequently correlated with higher peak anterior tibial shear force and thus ACL load. ACL strains have also been demonstrated to be proportional to quadriceps force and knee flexion angle, with peak strains occurring at around 30° of knee flexion. This is comparable to average

![Figure 3](image)

**Figure 3** — Sequence of events leading to a single-leg casting injury. DF indicates dorsiflexion.

<table>
<thead>
<tr>
<th>Athlete</th>
<th>Contact (pre/during)</th>
<th>Dorsiflexion (injured leg)</th>
<th>Knee flexion (injured leg)</th>
<th>Trunk extension</th>
<th>Landing from COM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Athlete 1</td>
<td>Pre; during</td>
<td>13.4</td>
<td>11.9</td>
<td>0.9</td>
<td>42.6</td>
</tr>
<tr>
<td>Athlete 2</td>
<td>Pre</td>
<td>11.4</td>
<td>22.8</td>
<td>16.6</td>
<td>35.6</td>
</tr>
<tr>
<td>Athlete 3</td>
<td>Pre; during</td>
<td>15.9</td>
<td>45.1</td>
<td>16.8</td>
<td>58</td>
</tr>
<tr>
<td>Athlete 4</td>
<td>During</td>
<td>17.7</td>
<td>0.6</td>
<td>12.9</td>
<td>36.3</td>
</tr>
<tr>
<td>Athlete 5</td>
<td>Pre</td>
<td>51</td>
<td>38</td>
<td>8.2</td>
<td>51</td>
</tr>
<tr>
<td>Athlete 6</td>
<td>Pre</td>
<td>15.5</td>
<td>21.6</td>
<td>~16.2</td>
<td>64.5</td>
</tr>
<tr>
<td>Athlete 7</td>
<td>No</td>
<td>2.6</td>
<td>16</td>
<td>2.8</td>
<td>45</td>
</tr>
<tr>
<td>Athlete 8</td>
<td>Pre; during</td>
<td>Obstructed</td>
<td>11.6</td>
<td>15.3</td>
<td>50.8</td>
</tr>
</tbody>
</table>

Abbreviations: ACL, anterior cruciate ligament; COM, center of mass; contact (pre/during), pre: player-to-player contact occurred prior to injury, during: player-to-player contact occurred during injury; dorsiflexion angle (injured leg), angle of tibia relative to the ankle axis on the injured limb; knee flexion angle (injured leg), knee angle relative to the hip and ankle on the injured limb; landing from COM, where the athlete’s foot landed relative to their COM; No, no contact occurred; trunk extension, trunk extension during time of injury (a negative value would indicate trunk flexion).
knee flexion angle observed in this study in the bilateral hop of 21°. Consequently, it can be speculated that an inadequate rate of hip flexion combined with a relatively lower hip extension to knee flexion angular velocity ratio, and a large quadriceps contraction contributed to the ACL rupture in the bilateral hop mechanism.

Figure 6 — Sequence of events leading to a bilateral hop injury. COM indicates center of mass.

Table 3 Descriptive of Aerial Contact With Single-Leg Landing ACL Injuries in the NBA

<table>
<thead>
<tr>
<th>Athlete</th>
<th>Injured with ball</th>
<th>Abduction angle (swing leg)</th>
<th>Knee flexion angle (injured limb)</th>
<th>Trunk lateral flexion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yes</td>
<td>113</td>
<td>23.3</td>
<td>15.5</td>
</tr>
<tr>
<td>2</td>
<td>Yes</td>
<td>75</td>
<td>28.8</td>
<td>Obstructed</td>
</tr>
<tr>
<td>3</td>
<td>Yes</td>
<td>82.9</td>
<td>35.2</td>
<td>26.1</td>
</tr>
<tr>
<td>4</td>
<td>Yes</td>
<td>97.9</td>
<td>39.3</td>
<td>Obstructed</td>
</tr>
<tr>
<td>5</td>
<td>Yes</td>
<td>146.8</td>
<td>44.5</td>
<td>17.2</td>
</tr>
<tr>
<td>6</td>
<td>No</td>
<td>115.9</td>
<td>Obstructed</td>
<td>30.2</td>
</tr>
</tbody>
</table>

Abbreviations: ACL, anterior cruciate ligament; injured with ball, had possession of ball during ACL rupture; abduction angle, abduction of leg not in contact with the ground; knee flexion angle (injured leg), knee angle relative to the hip and ankle on the injured limb; trunk lateral flexion, trunk lateral flexion during time of injury.

Figure 7 — Average leg abduction (noninjured leg) and ipsilateral trunk flexion of single-leg landing after contact injuries.

Figure 8 — Average knee flexion (injured limb) at midstance of single-leg landing after contact injuries.

The single-leg landing after contact mechanism involved a large angle of hip abduction in the noninjured limb, forcing the body COM into a counterbalanced position that was deployed to likely maintain balance. During this rotational transition in the flight phase, the injured limb made ground contact while the body was rotating toward the side of the affected limb inducing an internal rotation moment. Landing from a height increases axial...
compression, which has also been identified as a mechanism for ACL injury.21 In a specimen drop-landing simulation, Navacchia et al26 found that ACL strains were highly correlated with tibiofemoral contact forces on the lateral tibial plateau during impact. Furthermore, in the same study, knee abduction and internal tibial rotation, as well as anterior tibial translation, factors that have previously been identified in ACL strain,27 were all observed. Therefore, a combination of axial compression, altered balance, and trunk rotation toward the injured limb are likely contributors to the single-leg landing after contact mechanism.

Across all 3 mechanisms we identified in this study, two thirds involved a rapid internal tibiofemoral rotation at ground contact, presumably just prior to ACL rupture. Internal rotation of the tibia increases strain of the anteromedial bundle of the ACL and induces anterior tibial translation. The steeper posterior slope of the lateral tibial plateau causes the lateral femoral condyle to glide posteriorly more than the medial femoral condyle, creating medial tibial rotation under compression loading. This may be accompanied by some degree of knee valgus, but it is important to note that if valgus were to cause the ACL injury, medial joint opening would presumably just prior to ACL rupture. When combined with a large quadriceps contraction such as when decelerating rapidly, ACL strain may reach failure.26,27 Furthermore the combination of knee joint compression, flexion, and internal tibial rotation was identified as the "worst case" for peak ACL strain in a study simulating single-leg jump landing and pivot cut on an in vitro model.28

Previous research has examined ACL injury mechanisms in basketball players with video analysis,13 but the results differed from those shown here. Notably, it was found that athletes with greater knee and hip flexion angles upon landing were at the highest risk for injury, with injured males demonstrating lower flexion angles than females.13 Large hip and knee flexion angles at initial foot contact are not necessarily correlate to impact forces, but rather it is the active hip and knee motion.20 It is important to provide further context before interpretation of these results. First, striking well outside of the base of support with extension or lateral flexion of the trunk was observed in the majority of these injuries. This observation is supported by literature reviewing mechanism of ACL injuries.19,29 In fact, Koga et al19 found after film review of 10 ACL injuries in female handball and basketball that the foot position was anterior to the COM and contacted the ground with the heel strike in all cases. These findings would suggest that striking in front of the COM with a large ankle dorsiflexion angle created rapid braking forces. Moreover, if this occurs where the trunk is going through large ranges of motion, it disrupts that athlete’s equilibrium at touchdown and puts the athlete at risk for this type of injury.

Most of the ACL injuries (22/27) occurred alongside some form of opposing player-to-player contact prior to, or during, the ACL injury. During film review, 5 injury cases were the result of direct contact to the knee joint, but these were excluded from the analysis. The perturbation involved with encountering the mass of an opposing player may be a contributing factor in altering mechanical strategies during these maneuvers. A delay in co-contraction of the quadriceps and hamstring muscles has been proposed to be exacerbated by a sudden increase or decrease in load against which the muscle is contracting.21 When contact precedes the injury and is then removed, a sudden decrease in load may be experienced, while the opposite is true of contact occurring at the time of injury. Player-to-player contact is a component to the game that cannot be avoided, and athletes must exhibit strategies to dissipate the external energy associated with player-to-player contact and appropriate movement control and movement strategies that limit ACL loading. Failure to execute such strategies adequately may put the athlete at much higher risk for this type of injury.

Our findings can help practitioners identify training methods to reduce the risk of ACL injury. The technical development of these motor behaviors must be addressed in a controlled environment. First, as it relates to the single-leg cast and bilateral hop, athletes must be trained to demonstrate these maneuvers without excessively striking the ground outside of the base of support. Hip flexion should simultaneously accompany rapid knee flexion induced by the deceleration, and posterior trunk lean or trunk lateral flexion in the case of single-leg casting, should be avoided. In such cases, quadriceps strength, neuromuscular timing of the quadriceps and hamstrings in rapid deceleration, hip abductor strength, and motor control strategies that allow for hip flexion and not relative hip extension in deceleration, would all be considered important.20,21,28 If the athlete does not possess the physical requirements to execute these tasks appropriately, it may be difficult for the athlete to consistently perform these technical maneuvers safely, particularly while under cognitive load while having possession of the basketball, and with the influence of game fatigue. As it relates to aerial contact, this is a part of the game that is difficult to account for and extremely hard change in real time. However, athletes must have contingency when put in these positions to mitigate risk.

ACL injuries can be detrimental to NBA careers. It is important to understand the exact mechanism of these injuries if practitioners are going to be able to identify risk and train basketball
athletes in improving body mechanics during these maneuvers to decrease the risk of ACL injury. Demonstrating a commentary of mechanics is crucial in professionals having a technical model around reducing the likelihood of these injuries occurring within professional basketball. The data presented in this study can benefit practitioners who are seeking to mitigate ACL injuries in the NBA as each injury mechanism had unique kinematic features.

There were several limitations to this study. First, of the 105 documented injuries within our database, only 35 were available for film review. This leaves a large number that could have been unique mechanisms outside of the classifications that this present study observed, as well as outliers. The second limitation was that our film review was 2-dimensional in an uncontrolled setting. This presented the issue of obstruction of view due to teammates and opponents between the camera angle and the athlete.

ACL tears within professional basketball can alter career longevity and blunt performance. The present analysis provides important information for practitioners working with NBA athletes. The present findings from this study suggest that striking well outside the base of support is a contributing factor to ACL injuries within the NBA. Furthermore, indirect player-to-player contact was found in most injuries examined within this database. Future directions in understanding ACL injuries within basketball must take place to advance the sport forward. For example, investigating the distribution of known factors within this population will aid in better understanding potential risk in ACL injuries within the NBA. Also, of relevance is examining different basketball populations (ie, subelite, youth, female) to understand variance among the basketball world. Studying the mechanical demands associated with these traumatic injuries is pertinent in decreasing likelihood of occurrence and creating contingencies to protect the athletes during training and competition.

References


